Towards ψ-epistemic quantum gravity

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Abstract — This self-contained letter shows how ψ-epistemic quantum gravity (QG), that is, QG with a ψ-epistemic interpretation of quantum theory, in principle emerges from a deterministic model of the Elementary Process Theory (EPT) that describes an individual process at supersmall (Planck) scale by which a predominantly gravitational interaction takes place. While both ψ-epistemic QG and the model of the EPT remain to be formulated rigorously, this shows how the probabilistic nature of our knowledge of the physical world emerges in a strictly deterministic universe—God does not play dice, it is our knowledge of the outcome of a process that is fundamentally probabilistic.

1 Introduction

Let's begin by quoting the late Michael Dummett on quantum theory:

> "*Physicists know how to use quantum mechanics and, impressed by its success, think it is* ***true****; but their endless debates about the interpretation of quantum mechanics show that they do not know what it* ***means****.*" (emphasis original) [1]

These "endless debates" have by no means been settled in the meantime. The current situation is thus that on the one hand consensus exists among physicists that quantum theory is very successful in its area of application, but on the other hand that distinct interpretations of quantum theory coexist without there being an objective criterion to decide which is the best interpretation. An important distinction that we can make is between *ψ-ontic* and *ψ-epistemic* interpretations [2]. A ψ-ontic interpretation entails the view that the wave function represents a state in reality. In particular the most widely held interpretation of quantum theory, the 'orthodox' or 'Copenhagen' interpretation advocated by Bohr, entails the view that the wave function is a *complete* representation of a microsystem: this corresponds with the view that, absent certain special preparations, a particle doesn't have a definite position in absence of measurement [3]. A ψ-epistemic interpretation, on the other hand, entails the view that the wave function does <u>not</u> represent a state of a microsystem, but rather *what we know* of the microsystem. According to Fuchs,"[Einstein] was the first person to say in absolutely unambiguous terms why the quantum state should be viewed as information ..." [4].

That said, the purpose of this letter is to show how *ψ-epistemic quantum gravity* (QG), a quantum theory of gravity in which the wave function is a purely mathematical object that is instrumental in representing statistical knowledge of a Planck-scale system, emerges from a deterministic model of the Elementary Process Theory (EPT), introduced in [5], which is incompatible with *orthodox* quantum mechanics. The next section outlines the key features of a model of the EPT that describes a process at Planck scale by which a gravitational interaction takes place. The section thereafter shows how ψ-epistemic QG emerges from there. The final section briefly summarizes the conclusions.

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2 Key features of the process of gravitational interaction

The EPT has been developed from a thought experiment with the outcome that (massive) antiparticles are repulsed by the gravitational field of (massive) particles of ordinary matter. There are several theoretical arguments against a matter-antimatter repulsive gravity—see [6] for an overview—but the issue has not been settled definitely: there are at least four sizeable projects going on to experimentally establish the coupling of antimatter with the earth's gravitational field [7, 8, 9, 10]. That said, the EPT is a collection of seven elementary process-physical principles, which give a rather abstract description of the individual processes by which interactions have to take place for repulsive gravity to exist. Applying the method set forth in [11], currently a model of the EPT is in the works that is intended to reduce empirically to general relativity (GR)—here 'empirical reduction' is a notion introduced by Rosaler in [12], in casu meaning that the model of the EPT reproduces the empirically successful predictions of GR. One has to fully understand the implications thereof: if a model M of the EPT that *reduces empirically* to GR can successfully be developed, then any experimental outcome that at the time of the performance of the experiment was seen as experimental support for GR, provides *equally well* experimental support for M.

Although some details of the model of the EPT remain to be specified, we can already now sketch the process by which an ordinary matter particle (e.g. an electron) interacts with its surroundings such that the interaction has only gravitational aspects. Thus speaking, suppose that the rest mass m_0 of the matter particle remains constant and suppose that motion is confined to one spatial dimension; let's consider then the following process of interaction:

(i) the initial state is a point-particle with energy E_0, spatial momentum $p_0 = \sqrt{(E_0)^2 - (m_0)^2}$, and position x_0, which we can represent by a mathematical object $\psi_0 = \psi_0(E_0, p_0, x_0)$;

(ii) the initial event is a state transition $\psi_0 \rightarrow \psi_i$, by which the initial state ψ_0 transforms into an intermediate wave state ψ_i with energy $E_i \geq E_0$, which we may visualise as a wave progressing linearly (geodesically) with constant spatial momentum $p_i = p_i(p_0, \nabla\phi)$ where $\nabla\phi$ is the gradient of the gravitational field at x_0;

(iii) the final state is a point-particle with energy $E_1 \leq E_i$, spatial momentum p_1, and position x_1, which we can represent by a mathematical object $\psi_1 = \psi_1(E_1, p_1, x_1)$;

In this process a massive particle (such as an electron) alternates once between a particle state and a wave state: that way it undergoes a gravitational interaction; the final state ψ_1 is the initial state for the next process. See Fig. 1 for an illustration. Note that the initial event and the final state (with its definite position) occur independent of observation: this is incompatible with orthodox quantum theory.

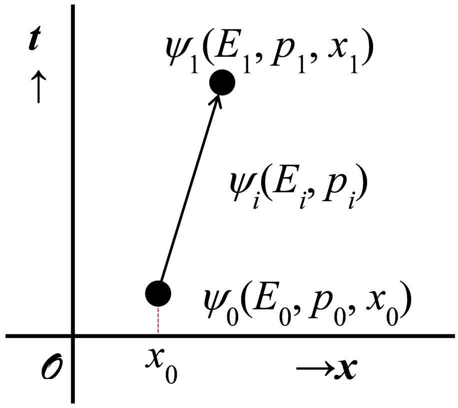

Figure 1: Illustration of the process of a gravitational interaction in the coordinate system of an observer $\mathcal{O}$. The upper and lower dot depict final and initial states at positions $x = x_1$ and $x = x_0$, respectively, and the arrow in between depicts the intermediate wave state. If $p_1 > p_0$ this gravitational interaction has resulted in acceleration; if $p_1 < p_0$ then it has resulted in deceleration.

3 Emergence of ψ-epistemic QG

Under these assumptions (no change in rest mass, motion in one spatial dimension) there are just two possibilities for how the final state ψ_1 can arise from the intermediate wave state ψ_i:

(i) in case of **acceleration** we have $E_0 < E_i = E_1$ and $p_i = p_1$, and the final state ψ_1 then simply arises from a state transition $\psi_i \to \psi_1$, so in this case the energy $\Delta E = E_1 - E_0$ required for the acceleration is absorbed from the surroundings at the initial event;

(ii) in case of **deceleration**, we have $E_0 = E_i > E_1$ and $p_i = p_0$, and the intermediate wave state then first transforms by a state transition $\psi_i \to \psi_i^*$ into an 'excited' particle state $\psi_i^* = \psi_i^*(E_0, p_0, x_1)$ at $x = x_1$, which instantly emits a photon γ with energy $E_\gamma = E_0 - E_1$ and thereupon transforms into the final state ψ_1 by a state transition $\psi_i^* \to \psi_1$.

That is to say: contrary to what is the case in the framework of classical mechanics where motion is continuous, in the framework of the EPT where motion is stepwise photons occur *naturally* due to discrete transitions in individual processes—deceleration in any spatial direction is accomplished by 'Bremsstrahlung'.

But now that we have photons flying around, a second type of process is possible in this universe with only gravitation: namely, a process in which in addition a photon is absorbed at the initial event $\psi_0 \to \psi_i$. Let's call this a 'process II', and let's call the process described in the previous section a 'process I'. Now suppose a process takes place with initial point-particle state $\psi_0 = \psi_0(E_0, p_0, x_0)$ at position $x = x_0$; if the process is a process I, the final state will be the state $\psi_1 = \psi_1(E_1, p_1, x_1)$ as before, but if the process is a process II then the final state will be a state $\psi_1' = \psi_1'(E_1', p_1', x_1')$ at *another* position $x = x_1'$ that depends on the momentum p_γ of the absorbed photon: $x_1' = x_1'(p_\gamma)$. See Fig 2 for an illustration.

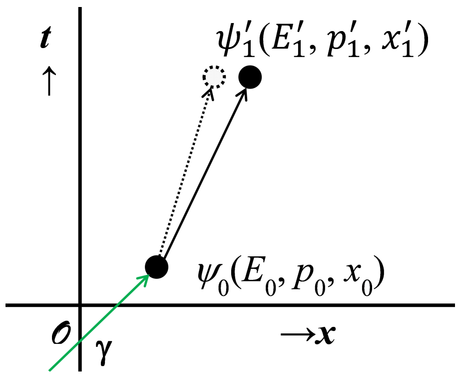

Figure 2: Illustration in the coordinate system of an observer $\mathcal{O}$ of a process II. The lower black dot depicts the initial state ψ_0 of the process. The dotted arrow and the dotted circle depict the intermediate wave state ψ_i and the final state ψ_1 at the position x_1 that would have occurred if the process would have been a process I as in Fig. 1. The green arrow depicts the incoming photon γ, and the not-dotted arrow and the black dot depict the intermediate wave state ψ_i' and the final state ψ_1' at a position $x_1' \neq x_1$ occurring in this process II.

That said, suppose we prepare a system made up of one particle—say, an electron—such that we *know* that its initial state is the particle state ψ_0 at position $x = x_0$ where the gradient of the gravitational field $\nabla\phi$ is known. Question: where will the *final state* ψ_1 of the upcoming individual process occur? There is then only one plausible answer: *we cannot possibly know that*. It is, namely, fundamentally impossible to build a device by which we "see" a photon coming towards the device—just think about it—and therefore there is no way of *knowing* that a photon will be absorbed at the initial event $\psi_0 \to \psi_i$: *all we know* is that we can expect the final state at a certain position x_1 if the upcoming process is a process I, but for every possible value p_γ of the momentum of a photon there is a probability that such a photon will be absorbed at the initial event of the process, which yields a process II with a final state at a position $x_1' = x_1'(p_\gamma) \neq x_1$.

Since there are just a finite number—say, N—of possible values for p_γ, there are in this example with motion in one spatial dimension thus a finite number of positions $x_1^1, x_1^2, \ldots, x_1^N$ to which we can attach a probability of finding the final state there: the probability of finding the final state at $x = x_1^1$ is P_1, the probability of finding the final state at $x = x_1^2$ is P_2, etc. These probabilities P_j are related to the corresponding photon densities, which are measurable, and of course we have $\sum_{j=1}^{N} P_j = 1$ since it is certain that we will find the final state *somewhere*.

Furthermore, we have to realize that this is at Planck scale: distances between consecutive values x_1^j, x_1^{j+1} are much smaller than the resolution of any measurement equipment: for practical purposes, the discrete probability distribution can therefore be *approximated* by a continuous function Ψ_1—we can expect this to be a Gaussian function with its maximum at the position of the final state of process I. If we do not measure the position of the final state ψ_1, then we must consider that each of the possibilities for the first process gives rise to again N possibilities for the second process. Thus speaking, to the final state ψ_2 of the *next* individual process another discrete probability distribution will be attached that we again can approximate by a continuous function Ψ_2: we can expect the latter to be a Gaussian function that is *wider* that the Gaussian function Ψ_1 associated with ψ_1, and we can expect that we can capture the change of Ψ_1 to Ψ_2 by a continuous temporal evolution according to some wave equation. The foregoing gives us the following ***preliminary*** postulates of ψ-epistemic QG:

Postulate 3.1. *To every Planck-scale system with position space X is associated a complex-valued wave function $\Psi : X \to \mathbb{C}$ with norm $\|\Psi\| = 1$.* ■

Postulate 3.2. *The wave function Ψ is nothing but a purely mathematical object that is instrumental in representing our knowledge of the Planck-scale system.* ■

Postulate 3.3. *The wave function Ψ of a Planck-scale system evolves continuously in time according to a gravitational wave equation for $\partial\Psi/\partial t$.* ■

Postulate 3.4. *For every region U of X, the probability P_U of finding the constituent of the Planck-scale system in U can be calculated from the wave function according to*

$$P_U = \int_U \Psi\Psi^* dx \tag{1}$$

■

These preliminary postulates only give the contours of ψ-epistemic QG, but the point here is that we have shown how these emerge from a strictly deterministic model of the EPT.

4 Conclusions

The main conclusion is that we now have a basic picture of how ψ-epistemic QG, a quantum theory of gravity with a ψ-epistemic interpretation of quantum theory, *in principle* emerges from a strictly deterministic model of the EPT that describes an individual process of gravitational interaction at Planck scale. This is significant, since the EPT is inconsistent with orthodox quantum mechanics.

Most physicists are familiar with the idea that probabilistic systems are deterministic under the surface—some have even speculated about a deterministic theory underlying quantum mechanics, e.g. [13, 14]. From that perspective one might find the present finding not very surprising. What distinguishes the present finding, however, is that it provides a missing link between gravitational physics and quantum theory at the conceptual level. By contrast, general relativity and orthodox quantum mechanics have been shown to be incompatible *at the conceptual level*, see e.g. [3].

Future research is first aimed at completing the model of the EPT that is to reduce empirically to GR. Thereafter attention can be focussed at developing ψ-epistemic QG; the bottom line is that this line of research can yield a proof that the EPT is a unifying scheme that has a model that reduces empirically to existing theories of gravity and electromagnetism.

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